AN INTEGRATED BUILDING SYSTEM

by
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Bachelor of Architecture, University of Illinois 1967

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF ARCHITECTURE
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
JUNE 1968

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June 17, 1968

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on Graduate Students
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ABSTRACT OF THESIS
AN INTEGRATED BUILDING SYSTEM
GENE HARROLD CLEMENTS

Submitted to the Department of Architecture on June 17, 1968 in partial fulfillment of the requirements for the degree of Master of Architecture.

In order to meet the growing demand for shelter for man and his institutions, architects must search for more efficient ways to design and build. This thesis is primarily concerned with the development of an integrated group of building systems to house a modern university. The main considerations in this project are the need for real flexibility in the physical and academic structures of the university and the need for efficiency of construction and use of space.

Because of the great demand for change in the physical environment of the university as exemplified by the recent need for such tools as wind tunnels, material testing areas, nuclear reactors and the like, the scheme makes a strong distinction between the permanent and temporary elements of the system.

The backbone of the system is the major, permanent structure. This is expected to last 100 years or more and is intended to allow change within it while remaining fixed, giving an order to the whole. This major structure consists of a grid of concrete trusses spanning 150 feet, the largest area permitted by the building code between fire stairs. Since fire stairs are required at these points, the walls surrounding them provide the major vertical structure. This yields the largest possible unimpeaded space. Within the major structure, a light steel system provides the usable floor surfaces, and is designed so as to be readily changeable. Due to the size of the major system, small usable spaces can be provided within the 10' deep structure, while the 30' vertical clearance between major structural girds allows for lecture halls or gymnasiums. By dividing this with a secondary floor of light prefabricated units, two floors of laboratories can be provided. Similarly, two intermediate floors provide three floors of offices or classrooms.

As new materials and techniques come into use, the light steel floor system can be replaced by plastic or whatever, without affecting the permanent system.

Thesis Supervisor: Yusing Jung
June, 1968

Lawrence B. Anderson, Dean  
School of Architecture and Planning  
Massachusetts Institute of Technology  
Cambridge, Massachusetts

Dear Dean Anderson:

In partial fulfillment of the requirements for the degree of Master of Architecture, I hereby submit this thesis entitled "An Integrated Building System."

Respectfully,

Gene Harrold Clements
ACKNOWLEDGEMENTS:

The author wishes to thank Professor Eduardo Catalano, Professor Waclaw Zalewski, Professor Yusing Jung, and his fellow students in the graduate class, for their constructive criticism, encouragement, and enthusiasm.
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INTRODUCTION

The twentieth century is a challenging time for the architect. On one hand the architect has better technology, materials, and procedures than ever before. On the other hand the rapid growth of the population and its institutions make larger and larger demands on the architect's imagination and knowledge. He is called upon to make better environments for larger numbers of people. He must make them more adaptable, build them faster, and at less cost. These demands make it necessary for architects to search out new and meaningful solutions to these problems.

This project is concerned with the development of a prototype set of building systems, fully integrated, each capable of being constantly renewed, keeping up with the advances of the future, yet providing a unified whole, a basis for an orderly pattern of growth.

There are two long range goals inherent in this project: first, to come to a greater understanding of the nature of a building system, and second, to devise a building system, hopefully contributing to the knowledge gained by the graduate class at MIT in their exploration of various systems over the past few semesters.

In order to assume certain programmatic requirements, the system will be designed to house the typical requirements of a university. This choice of use is especially challenging in
view of the great need for change in a university physical plant, as well as the continuous growth which so often is totally haphazard and unrelated to the concept of the university as a whole.

PROGRAM

BASIC

The program requirements come from several sources. The basic program is the creation of a building system, integrating structure and mechanical elements of the building, and providing for flexibility of change and orderliness of growth, based on self-sufficient building units. Implicit in the basic program is the requirement that the system be suitable for the use which it was intended, requiring a thorough examination of the requirements of the building type selected. The basic program also requires that the system conform to a typical building code.

DETAILED PROGRAM

In order to establish criteria to work with, a program for a specific type of building was written. In this case, the use selected for the system is the university building. The reason for this choice is that it offers the most challenge in view of the wide variety of spaces needed, the various mechanical systems that must be provided for, and, most important, the very severe need for changeability.
It was assumed that a basic system for a university building should provide for the following uses:

1. Offices
2. Seminar rooms
3. Class rooms
4. Drafting rooms
5. Rooms for painting, sculpture, etc.
6. Lecture halls
7. Meeting rooms
8. Library
9. Laboratory spaces for a great variety of uses
10. Eating places
11. Lounge areas
12. Galleries
13. Gymnasiums
14. Other athletic facilities
15. Parking areas
16. Special purpose areas

The system is not intended to include dormitory, apartment, or other living units.

BUILDING CODE REQUIREMENTS

The part of the building program which comes from the building code is too large and complex to be fully covered in this report. In general, the building code was used to determine certain safety standards relating to occupancy and fire exits.

The requirements given by the building code which directly affect the design of the system are the following: The horizontal distance to an exit stairway may not exceed 150' along the line of travel. In some cases where high hazards are found, this distance is limited to 100' but may be increased to 150' if the building is sprinklered.

Based on an average mixture of uses, the required number and size of exits would be 1 exit width for every 80 persons.
A BUILDING AS A SYSTEM

Any building is comprised of two parts. First, a building consists of certain units of space, which are of such a size and shape so as to be usable for some activity of man. Second, a building is comprised of structural, mechanical, and circulation systems, which form the framework into which the usable spaces are placed, and which provide services or circulation to these spaces.

Since our motive for building is to create the spaces which are usable for the activity we have in mind, it seems reasonable to draw two conclusions. First, that the usable spaces should weigh more heavily than the service elements in design decisions, and second, that the service elements should be as efficient as we can make them so as to yield as much usable space as possible.

Our first job is to determine what sorts of usable spaces we need. Looking at college buildings today, it can be seen that many different sizes and shapes of spaces are used. These vary from the 10' x 10' office to the large auditorium with its sloped floor to the giant gymnasium and assembly hall. Whatever system we devise must accommodate a great range of sizes of spaces. If the building were to be used throughout its lifespan in the same way it was to be used at the beginning, we could simply design our system to accommodate the exact sizes needed. There is,
however, a complication. If the structure is capable of lasting 100 years or longer, the building may well be changed to provide for uses which we have no idea of now. Who could have predicted, for example, in 1868 that within 100 years college buildings would contain wind tunnels, nuclear reactors, huge material testing machines, study carrells, and so on. The December 14, 1967 issue of "Tech Talk" notes that here at MIT "an enormous laboratory, created by opening a series of double doors, extends the 200 foot length of the center for Space Research. The sheer size of the experiment that could be constructed there staggers the imagination. This will provide modern working conditions for students and faculty in seventeen departments as they probe the mysteries and problems of space." It seems questionable, at best, to assume that the spaces we require in colleges today will not change radically in the next 100 years. This point has been stressed by Casson and Conder in the University of Birmingham Development Plan:

It is a truism that a university is a society founded for the advancement of learning and the dissemination of knowledge. This means that it is constantly changing, always on its way, its work never completed. Departments expand, contract, quadruple in size, or virtually disappear within a few years, often in defiance of the most knowledgeable and expert forecasts. Every building and each layout, so optimistically and thoroughly designed, seems to become within a decade not only out of date but physically hampering to the future. Any attempt therefore to constrict its movement artificially, either academically or physically, seems doomed, and rightly doomed, to failure.
Buckminster Fuller, in a speech to those engaged in planning the Edwardsville campus of Southern Illinois University, urged the committee along the same lines:

I would counsel you in your deliberation regarding getting campuses ready now to get general comprehensive environment controls that are suitable to all-purposes like a circus. A circus is a transformable environment. You get an enclosure against "weather" that you can put up in a hurry, within which you can put up all kinds of apparatus—high trapezes, platforms, rings, nets, etc. You can knock it down in a few minutes. That is the way the modern laboratory goes. In laboratories you can get the generalized pipette or whatever it is, the crucible, and the furnace. You can put the right things together very fast, rig them up, get through the experiment, knock it down. It's one clean space again. You want clean spaces. The circus concept is very important for you.

Anything that is static, forget it. Work entirely toward the dynamic. Get yourself the tools and ways of enclosing enormous amounts of space, and make it possible for huge numbers of human beings to come together under more preferred conditions than have ever before come together.2

Considering the fact that we can not determine the exact size or requirements for our spaces, the best condition would be an infinite space, with no structural or other infringements to inhibit our planning. Since this is impossible one must look for the given condition which will impede the infinite space we would like. The building code requires that fire stairs be located not more than 150' from any point along the line of travel. In satisfying this requirement no unimpeded space can be larger than 150' square. Since there must be a stair at these points, this impingement acts also as the vertical
Having tentitively chosen a 150' bay, we want to see how well it suits other requirements. This size bay has several happy consequences. First, the depth of structure needed to span 150 feet is such that small usable spaces can be gained within the structure. In the case of the smaller bay and its thinner structure this space is lost. The ratio of the depth of structure to usable depth below is set at the same ratio as found in a smaller bay, thereby making the added space within the structure, a bonus. The width of the column element makes the strip connecting them of a suitable size that vertical mechanical circulation can take place within this strip, thereby never interfering with the bay itself, and because this core can be located on any of the four sides of the bay offers almost no hinderance to planning. Choosing this scale of structure, the other floors can be built of light material which can be changed easily, and the span of which can be adjusted to suit more exactly the requirements for each case. This scale provides the mechanical space which is large enough to provide excellent space for changing or servicing the mechanical equipment.

Knowing the approximate size of the basic unit it can then be broken down and investigated as to the planning of the bay itself. In this scheme, a 5' x 5' x 1'-6" planning module was adopted. There are several reasons for this. The 5' x 5' x 1'-6"
module is well suited to receive various components used in building construction, for example this module allows for a horizontal structural member and a standard four foot fluorescent tube to occupy one module. Additionally, the furnishings of buildings often fit into this size, i.e. 2 chairs, a man at a desk, and so on. Vertically, the planning module has been set at 1'-6". This accommodates many of the standard heights associated with buildings, handrails at 3 feet, man at 6 feet, ceilings at 7'-6", 9'-0" or 12', truck clearances at 15' and auditoriums and gymnasiums at 30'.

LIFE IN THE BUILDING

One of the greatest hazards in an approach which relies on repetition of elements and dimensions is the tendency for it to become sterile and uninteresting. Architecture gets its life from variety, interest, and boldness. The use of a large scale permanent structure, gives the system boldness and interest, especially when it is exposed, or when its ability to accommodate very large spaces is taken advantage of. While one can relate to the overall order created by the permanent structural system, the changeability of the secondary structure allows a great deal of variety from space to space and from year to year. One can sense a larger, ordered framework, even when his immediate vista may be quite interesting.

The use of the space within the major grid for offices and meeting rooms, yields some very exciting spaces when the trusses are exposed.
DESCRIPTION OF THE SYSTEM

The system has two, clearly defined parts; the major, permanent system, and the minor system, which can be changed to fit the requirements of specific uses either as the building is being constructed or at any time in the future. By changing the scales of the permanent vs. the temporary parts of the system from the normal, a greater degree of flexibility, the major requirement of a college building is obtained.

THE MAJOR STRUCTURAL SYSTEM

The major structural system is the backbone of the system. (See page D1) It consists of a 150' square bay, made up of a 30' grid, supported on perimeter girders, which in turn are supported on 20' square hollow columns. The structural grid is 10'-6" deep, and spaced at 30' clear vertically. (See page D3) The hollow columns contain the only permanent vertical requirement, the fire stairs. Using this megastructure, the individual spaces can be tailored more exactly to the needs of their occupants, while the same basic ordered system will accommodate the widest possible range of uses.

The components of the major structural system are these: the poured-in-place columns using precast concrete formwork which is not removed; the perimeter girders of concrete, precast and post tensioned at the site; the structural grid of 150' long, 10'-6"
deep beams, and 30' long 10'-6" deep beams also precast and post tensioned at the site; and 20' long, 1'-6" deep beams at the top and bottom of the space between the double girders which hold the grid members in continuous action, and allow for cantilevers.

Concrete was chosen for the major structural system because of its fire resistance, its permanence, and its boldness, especially in large units. Additionally, concrete allows the material to be brought to the site easily, while precasting at the site eliminates much of the messy and complicated formwork, precariously built on scaffolding. By precasting at the site nearly all of the advantages of precasting in the factory can be obtained especially on a large job such as a university, while the difficult shipping of large, somewhat fragile pieces is eliminated.

THE MINOR STRUCTURAL SYSTEM

The actual working surfaces within the system are provided by the minor system. Ideally, any requirement which would have to be met at a later date, or new materials which may come into use during the life span of the building could be accommodated in the minor system without requiring a complete demolition. It is possible, within the framework provided, to design other systems, in addition to the ones mentioned, should the need arise. The basic minor system consists of an intermediate floor level which is suspended from the grid above, or supported on one story high columns from the floor below. In this way, a very large uninterrupted
area can be created if desired, or vertical structure can be placed on 30' or 60' centers to suit the particular use, the minor structure varying with the span desired. This minor system of surfaces is made up, as one initial variation, of light weight steel space frames, (see page D3) allowing local mechanical and electrical distribution to run through the slabs. These steel space frames are made in 5' x 5' square sections, and bolted in place, providing easy change, and allowing holes to be provided in the system at any point, for vertical connection between laboratories, offices, libraries and so on. Each space frame is light enough and small enough to be brought into the building and installed without the use of power equipment, and with a minimum of disruption. The edge of each unit provides a slot which receives a partition, or an air diffuser, or alternately, this slot is closed with a closure strip.

CORES

In this system, the cores are located in the 90' center of the 20' wide strip between the columns, leaving 30' between each end of the core and the columns to accommodate the circulation system. (See page D1) This way the cores never interfere with the total structural integrity of the bay, the mechanical distribution takes place in the center of the bay, its most logical position, cores always border the major circulation ways, and the number of cores can vary to suit the requirements of each bay. The cores consist only of vertical holes in the system, accommodating-
mechanical ways, elevators and plumbing. (See page D4)
In some cases, this space is taken up with escalators. The
enclosure of these vertical ways is non-structural, allowing
easy change, access for repairs, and eliminating a usual
point of conflict with the structure.

PERMANENT MECHANICAL SYSTEM

Since many advances can be anticipated during the next
few years in the field of environmental control, no part of
the mechanical system is "permanent" in the same sense as the
major structural system. In the case of the mechanical systems,
the "permanent" part of the system is designed to be changed
only during general remodeling of the system, while the temporary
systems are designed to be modified without a general upheaval
of the functioning of the building.

The mechanical system is fed from the cores, (see page D5)
with the major horizontal distribution occurring in the center
sub bay through the 10'-6" deep structural depth. The source
of the mechanical supply is the mechanical room, located either
in the penthouse, the basement, or within the major structure
itself.

The system is designed to bring light, power, air, plumbing,
and communication to any 5' x 5' module yielding the greatest
flexibility for division of space.

FLEXIBLE MECHANICAL SYSTEM

In general, the paths of services to the individual areas
of the building are as flexible as possible. In this way, small scale changes can be made easily with a minimum of interference with other areas of the building. Additionally, repairs can be made to small parts of the system without affecting the operation of the system as a whole.

AIR CONDITIONING

The air conditioning system is based on a high velocity single duct system with terminal reheat, which is brought up vertically through the core and distributed horizontally down the center of the bay. The air is then fed into a pressure reducing box, containing, if desired, a reheat unit if control is desired in units of one sub bay. The air reaches the room through low velocity ducts along the major beams (leaving room for usable spaces), and finally through flexible ducts running through the light steel floor system. By locating the pressure reducing valves in the center mechanical sub bays, the noise created can be absorbed easily, making acoustical control of the individual rooms easier.

In the cases where three intermediate floors are used between each major structural grid, the air conditioning ducts run up through the required partitions to outlets near the ceiling. Since both walls and diffusers are adaptable to the same slot between the small sections of the light steel structure, this is easily accomplished, the wall acting as an extension on the diffuser.
All air conditioning requirements were calculated on the basis of 2 cfm per square foot. This is considered to be a maximum value, and would typically be less, thereby assuring adequate mechanical space.

PLUMBING

Like the HVAC, all plumbing lines run vertically in the cores, following much the same pattern as the air distribution. In the cases where plumbing is required in intermediate floors, a thicker steel floor depth is provided, or the pipes are run vertically down to the major grid at some convenient point.

LIGHTING

Each module is capable of accepting a variety of ceiling panels, incorporating 2 or 4-4' fluorescent tubes. Incandescent down lights, or special lighting can be incorporated if desired. The use of two, four foot, 40 watt fluorescent lamps in alternate modules for example would yield a 65 foot candle light level in an average classroom.

Additional light can come from a flexible type lighting system such as a Litespan track, incorporated into the closure strip between ceiling panels.

Natural light is provided for by incorporating skylights into any of the 30' square sub bays, or any individual 5' x 5' module.

POWER / COMMUNICATIONS

Power and communication lines travel vertically in the cores
from the major electrical room in the basement. Each core contains a breaker panel at each floor, serving a portion of the bay. Horizontal distribution again follows the same pattern as the mechanical distribution, to its final availability point at each module.

ACOUSTICS

The problem of acoustical control is often acute in exposed concrete buildings. Reverberation is controlled by the acoustically absorbant panels in the ceiling construction, helping to isolate sound due to the weight and density of material needed to provide a fire rating. A great deal of sound diffusion is gained by the fact that the ceiling is not a flat plane, but an irregular surface created by the design of the lighting.

In addition, soft furnishings such as carpeting and curtains also add to sound absorption.

ERECTION PROCEDURE

The erection procedure for this system is as follows:
First, the precast concrete formwork for the columns is placed, the column reinforcing is installed, and the first section of the column is poured. These ends of the girders are cast integrally with the columns to provide continuity. Second, the girders, precast at the site, are lifted into place, supported on point scaffolding, and post tensioned. Third, the beams which separate the double girders are installed and post tensioned. Fourth, the main beams are placed on the girders one way, post
tensioned, and grouted. Fifth, the 30' infill beams in the main grid are placed and post tensioned. Sixth the temporary parts of the system are installed as required.

CONCLUSION

There are two basic reasons for the scale and pattern of the elements of the system. First, the wide variety of sizes and types of spaces required by the educational processes, and second, the difficulty or impossibility of predicting for certain the sorts of spaces which will be required by colleges in the future. This leads to the desirability of a larger than usual system network which can accommodate the large spaces in use now as well as the ones which may be required in the future, and to the desirability of increasing the temporary elements of the system, and decreasing the permanent elements as compared to the typical solution. It is also desirable to establish a clear distinction between the permanent and changeable elements of the system.

In choosing the megastructure system, the following advantages are gained as compared with a smaller scale system: Provision is made for large spaces within the system, each space can be tailored to fit very closely the needs to which it will be put, the use of the minor system provides for easy change within the system, the cores can be located only where necessary, and
never interfere with the bay itself, and small spaces can be gained in the structural depth that is typically too small to use and is hence wasted.

Further, calculations have shown the weight /sq. ft. of this system, assuming one floor between each structural grid, to be 160# as compared to 150-200# for most of the previous schemes.

There are, of course, problems caused by the large scale of the system. Growth can take place only in large increments, although this is partially offset by the fact that it is doubtful if a university would add to its space in small increments regardless of the system because of the cost of contracting and inconvenience of construction. This disadvantage is further offset by the possibility of accommodating growth within the existing structure by the ease of remodeling to gain more efficiency.

Construction of the larger structure is another problem, with the largest elements weighing up to 80 tons. With the present technology, however, this does not seem to be a grave drawback.

In short, this system combines the usual elements in a different scale, and pattern, gaining adaptability, suitability for a wide variety of uses, and a more efficient use of space, and sacrificing the possibility of small scale developments.
ADAPTABILITY TO AUTOMATIC COMPUTATION

The computer offers a valuable tool to the architect, particularly in those areas which lend themselves to quantitative analysis. In order to explore the possibilities for computer analysis of the quantitative aspects of the system, the masters class as a whole wrote a program for the IBM 1130 computer, relating the following variables:

- Structural module
- Bay size
- Depth of structure
- Area of columns
- Area of steel in structural members
- Area of concrete in structural members
- Loading conditions
- Weight of reinforcing steel
- Weight of concrete
- Size of mechanical supply and return
- Lighting and illumination requirements
- Building code requirements

These variables can be related in any of three structural variations, covering most of the basic structural configurations used by the students for the last several semesters.

This program enabled the class to investigate many possible solutions of the same basic type. Using the computer as an aid, yielded information about the implications of any changes that were made, and allowed an examination of the effect of various parameters on the system as a whole.
1. FOUR COLUMNS

2. FOUR CANTILEVERED GIRDER ENDS

3. PLACE GIRDER & DIAPHRAGMS

4. PLACE MAIN BEAMS ONE WAY

5. PLACE MAIN INFILL BEAMS & POST TENSION GRID

6. PLACE LIGHT STEEL FLOOR SYSTEM

TYPICAL BAY / CONSTRUCTION SEQUENCE
FOOTNOTES


2 R. Buckminster Fuller, *Education Automation*, page 85-86.

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